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The effects of foot morphology and anthropometry on unipodal postural control

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Abstract—The maintenance of posture is a constant challenge for the body, as it requires rapid and accurate responses to unforeseen disturbances, which are needed to prevent falls and maintain balance. The purpose of the present study was to compare different types of plantar arch in relation to postural balance, and analyze the relationships between variations the plantar arch and anthropometric characteristics of the feet with unipedal static balance. We evaluated 100 men and women between the ages of 20 and 40 years old, to determine anthropometry and posturography with a force platform. There was a weak correlation between plantar arches and anthropometric measurements and postural balance, except for the length of the male foot, which showed a correlation between increased size and poorer static balance. We conclude that the type of plantar arch does not influence postural balance, and of the anthropometric factors, only foot length was related to postural balance.

Keywords: postural balance, anthropometry, plantar arch.

Introduction

Maintaining posture is a constant challenge for the human body, as it requires rapid and accurate responses to unforeseen disturbances, particularly in unstable situations, which are needed to prevent falls and maintain balance. Awareness of the body's position in space is determined by the integration of the visual, vestibular and somatosensorial systems (Alonso *et al.*, 2012; Riemann, Myers, & Lephart, 2003). And the study of postural control is important for diagnosing balance disorders, as well as for assessing the effects of both therapeutic interventions and fall prevention programs (Alonso *et al.*, 2012; Kejonen, Kauranen & Vaharanta, 2003; Molikova *et al.*, 2006). One of the tasks related to postural control is the ability to maintain an upright, erect position (i.e., to maintain the projection of the center of gravity within a support base defined by the position of the feet).(Alonso, Greve & Camanho, 2009; Alonso *et al.*, 2012)

Various anthropometric and morphological characteristics may influence a person's base of support, and thus affecting the static and dynamic balance. Although often neglected in research, these factors must be taken into consideration in order to prevent errors of analysis and/or misinterpretation of the results (Alonso *et al.*, 2012; Cote, Brunet, Gansneder & Shultz, 2005). Studies have shown, for example, that changes in morphological characteristics of the different foot types (supinated, pronated and neutral) can influence balance (Cote *et al.*, 2005; Ferreira, Gave & Silva, 2010; Tsai, Yu, Mercer, & Gross, 2006). According to Cote *et al.* (2005) differences in foot types have a minimal effect on static balance. Yet, in another study, Tsai *et al.* (2006) found significantly compromised static balance in individuals with pronated and supinated feet compared with those with neutral feet.

Alonso *et al.* (2012) and Cote *et al.* (2005) reported that balance measurements should be controlled in order to avoid errors in analyzing the results, and suggest that anthropometric factors also be included in this type of evaluation. Studies seeking normative data for variables that might influence balance are needed, since there is no consensus regarding the contribution of anthropometric factors on postural balance. Specifically, there have been very few studies which have explored the contribution of anthropometric characteristic of the feet on postural balance.

Therefore, the purpose of this study was to compare different types of plantar arches in relation to postural balance, and analyze the relationship between variations the plantar arches and anthropometric characteristics of the feet with unipedal static balance.

Methods

Participants

One hundred men and women, aged 20-40 years old, who did not practice regular physical activity, were evaluated (n=50 women 26.4±5.1 years old, and n=50 men 28±6.1 years old). All the participants gave their written informed consent to participate in this study, which was approved by the University of São Paulo Medical School (# 1256/06). The inclusion criteria were: (1) no history of injury or surgery to the lower limbs or trunk; (2) not engaged in regular physical activity over the previous six months, as defined by the International Physical Activity Questionnaire (IPAQ); (3) absence of any disease or functional impairment of the auditory, vestibular, or proprioceptive systems; and (4) no current use of medications that might affect postural balance.

Procedures

The anthropometric measurements were performed in accordance with the International Society for the Advancement of Kinanthropometry (ISAK) standard (Clarke, 1993). Foot length was measured from the extremity of the heel to the extremity of the hallux. Foot width was measured by the distance from the 1st to the 5th metatarsal, and ankle width was measured as the distance between the medial and lateral malleoli. All the measurements were performed by the same evaluator, using a metric tape measure and a pachymeter both from Sanny (Brazil). The evaluation of foot angle was based on the footprint, standing on two legs, with bilateral distribution of load, using a pedigraph. Next, the Clark angle, or alpha angle (angle α) was calculated indirectly, from the footprint made (Figure A). For the measurement of alpha angle (α) a straight line was drawn from point A (head of the first metatarsal) to the point that corresponds to the apex of the concavity of the arch. The angle between the straight line A-A' and this perpendicular straight line is the angle Clarke (1993) (see Appendix). Using a planimeter, the Plantar Arch Index was calculated: An angle A' and feet with angles of between 0 and 29.9° are considered flat; from 30° to 34.9°, as low-arched; from 35° to 41.9°, intermediary, and above 42°, as high-arched.

The balance assessment (posturography) was performed on a portable force platform (AccuSway Plus, AMTI®, MA, USA). For data acquisition, the force platform was connected to a signal-amplifying interface box (PJB-101) that was linked to a computer by means of an RS-232 cable. The data were gathered and stored using Balance Clinic1 software, configured to a frequency of 100 Hz with a fourth-order Butterworth filter and a cutoff frequency of 10 Hz. All subjects assumed a unipedal position with the arms suspended alongside the body and the eyes fixed on a point located at a distance of one meter. Three measurements were performed for 30 seconds each. The arithmetic means of the results were calculated from the three tests conducted under each condition. The parameters used to measure the subjects' stability were: root mean square of the displacements from the center of pressure (COP) in the medial-lateral plane (XSD) and anterior-posterior plane (YSD); mean velocity calculated from the total displacement of COP in all directions (VAvg); and elliptical area encompassing 95% of displacement from the COP. (Alonso *et al.*, 2012)

Statistical analysis

The data was stored and analyzed in the SPSS 20.0 software. The Kolmogorov-Smirnov test was used to ascertain whether the continuous variables presented normal distribution. For comparison between different types of plantar arches and static postural balance the Kruskal-Wallis test was used.

Spearman's correlation coefficient was used to correlate the dependent variables (posturographic parameters) with the independent variables (anthropometric foot characteristics), in the whole population and separated according to gender. An alpha of 5% was used for all statistical tests.

Results

The anthropometric foot characteristics of the volunteers are described in Table 1.

Table 1. Mean and standard deviation of the anthropometric foot characteristics.

Variable	Combined Group M (sd)	Group Females M(sd)	Group Males M(sd)
Foot Length (cm)	24.2(1.7)	22.8(1.1)	25.5(1.2)
Foot Width (cm)	8.2(0.7)	7.8(0.6)	8.6(0.5)
Ankle Width (cm)	5.0(0.5)	4.7(0.4)	5.2(0.4)

The correlation between foot length and foot width was 0.69 ($P \leq 0.001$). Of the 100 individuals, 57 had similar feet (i.e., they presented the same type of plantar arch in both feet), with the remaining 43 showing differences in arch between the right and left feet. The distribution of plantar arch types among the volunteers is shown in Table 2.

Table 2. Descriptive analysis of the plantar arches characteristics.

	Combined Group F (%)	**Male Group F (%)**	**Female Group F (%)**
Flat (0 to 29.9°)	24 (12)	3 (3)	20 (20)
Low-arch (30° to 34.9°)	40 (20)	1 (1)	40 (40)
Intermediary (35° to 41.9°)	42 (21)	15 (15)	27 (27)
High-arch (≥42º)	94 (47)	81 (81)	13 (13)

Caption: F= frequency; % percentage

In the comparison between variation in plantar arches and static postural balance (stabilometric parameters), no significant differences were found (Table 3).

Table 3. Comparative table of the types of plantar arches and the balance data.

	Flat Foot Medi-an	**Low-arch Foot Median**	**Intermedi-ary Foot Median**	**High-arch Foot Median**	**p**
Medial-lateral sway (cm)	0.43	0.44	0.46	0.47	0.51
Medial-lateral ampl sway (cm)	2.47	2.48	2.50	2.59	0.49
Anterior-posterior sway (cm)	0.65	0.67	0.65	0.62	0.63
Anterior-posterior ampl sway (cm)	3.44	3.52	3.38	3.39	0.93
Sway Velocity (cm/s)	3.04	2.81	3.03	3.1	0.65
Sway Area (cm2)	5.39	5.81	5.56	5.5	0.90

There was a positive correlation only between the length of the legs and postural balance in men who influenced the results in combined group. On average, individuals with longer feet had greater oscillation in the anterior-posterior and medial-lateral planes, and the area of the combined group (table 4).

Table 4. Correlation between the anthropometric measurements of the foot and balance, N=200 feet.

	Angle (°) r(p)	**Foot Length (cm) r(p)**	**Foot width (cm)**	**Ankle Width (cm)**
Combined group				
Medial-lateral sway (cm)	.77 (.28)	.22 (.00)*	.08 (.22)	.04 (.53)
Medial-lateral ampl sway (cm)	.06 (.33)	.22 (00)*	.09 (.19)	.04 (.50)
Anterior-posterior sway (cm)	-.06 (.33)	.15 (.02)*	.02 (.74)	.01 (.82)
Anterior-posterior ampl sway (cm)	-.04 (.49)	.15 (.02)*	-.02 (.72)	-.02 (.76)
Sway Velocity (cm/s)	.12 (.07)	.19 (.00)*	.02 (.68)	.06 (.38)
Sway Area (cm2)	.00 (.97)	.22 (.00)*	.08 (.25)	.04 (.55)
Female group				
Medial-lateral sway (cm)	-.01 (.89)	.01 (.88)	.02 (.80)	-.09 (.37)
Medial-lateral ampl sway (cm)	-.03(.70)	.06 (.54)	.02 (.82)	-.08 (.38)
Anterior-posterior sway (cm)	-.12 (.21)	.08 (.43)	.06 (.53)	-.12 (.22)
Anterior-posterior ampl sway (cm)	-.95 (.35)	.09 (.35)	-.11 (.25)	-.09 (.33)
Sway Velocity (cm/s)	.11 (.25)	.05 (.56)	-.12 (.22)	.03 (.75)
Sway Area (cm2)	-.12 (.22)	.68 (.50)	-.25 (.80)	-.11 (.25)
Male group				
Medial-lateral sway (cm)	-.04 (.68)	.32 (.00)*	.02 (.84)	-.06 (.50)
Medial-lateral ampl sway (cm)	-.03 (.69)	.27 (.00)*	.02 (.83)	-.06 (.52)
Anterior-posterior sway (cm)	-.11 (.24)	.29 (.00)*	.00 (.94)	-.05 (.59)
Anterior-posterior ampl sway (cm)	-.10 (.31)	.27 (.00)*	-.06 (.52)	-.08 (.43)
Sway Velocity (cm/s)	-.09 (.37)	.15 (.13)	-.08 (.42)	-.18 (.06)
Sway Area (cm2)	-.10 (.32)	.36 (.00)*	.02 (.78)	-.01 (.91)

Spearman's correlation, * p≤0.05
Legend: ampl- amplitude.

Discussion

Considering that the foot is the base of support in all orthostatic positions, there are several factors related to foot morphology that may influence balance. However, there have been very few studies to determine the relationship between foot types and balance, and the ones that do exist have failed to include anthropometric characteristics of the feet such as width and length. Clarke (1993) analyzed the angle foot, as this is a simple technique that is well-described in the literature. Moreover, static posturography has also been examined, by Swanenburg, Bruin, Favero, Uebelhart and Mulder (2008), using the center of pressure (COP) oscillation on a force platform, and defined as the point of application of the result of the vertical forces acting on the support surface. (Corriveau, Hébert, & Prince, 2000).

Our findings suggest that morphological variation in plantar arches seems to have no effect on static balance, which corroborates the data of Cote *et al.* (2005) and Ferreira *et al.* (2010). However, in both previous studies, the investigators used other forms of classifications of the foot. Hertel, Gay and Denegar (2002) found that the area of displacement of the COP was higher in individuals with high-arched foot, and Tsai *et al.* (2006) reported that individuals with pronated and supinated feet showed higher postural oscillation than those with neutral feet. However, these studies did not evaluate the anthropometric measurements of the feet, particularly length, which may have influenced the results.

In the combined group analysis, greater foot length was associated with higher stabilometric parameters, with the exception of COP speed. Interestingly, when the data were stratified by gender, these results were found only in the male group. This has been shown in other studies and is likely due to the larger feet among men (Kejonen *et al.*, 2003; Molikova *et al.*, 2006) The higher oscillation of the COP (area and amplitude of displacement) in the male group may have been simply due to a greater surface area of the platform being occupied. This certainly does not necessarily indicate poorer balance and a higher risk for falls, especially given that there was no increase in COP speed. In fact, previous studies by Alonso *et al.* (2012) and Chou *et al.* (2009) demonstrated that an increase in the size of the support base can improve the balance.

Although we found a positive correlation between the foot length and the foot width (r=0.69 $P\leq$0.001), neither of these measurements seemed to influence balance. This contradicts the findings of Chiari, Rocchi & Capello (2002) in which foot width was related to balance. However, that study was conducted by bipedal standing balance task.

The methodological limitations of this study can be attributed to the multifactorial characteristics of balance. The systems used to evaluate vision, labyrinthine activity and the associated neuromotor responses, integrated with posturography and analysis of COP, may be more suitable for evaluating balance. However, our results suggest that there is a need to analyze foot length, in studies of static balance with posturography, in a young population.

Conclusion

Postural balance was not influenced by plantar arch type, independent of gender. Related to anthropometric factors only the foot length was influenced by unipodal static balance in males.

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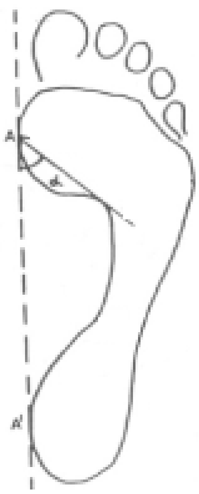
Appendix

Figure A. Parameters to calculate Clarke angle (α).



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